

EE-527: MicroFabrication

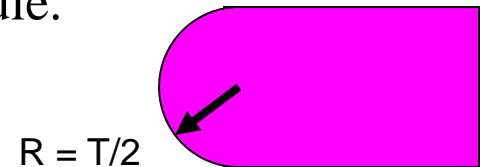
# Wafer Handling and Cleaning

# Terminology

- Wafer
  - a complete round disk of the semiconductor, usually cut from a grown crystal boule.
- Slice
  - a fraction of a wafer that has been reduced in size by cleaving, e.g. a half, quarter, or small rectangular piece which can still undergo some processing.
- Die
  - an individual part from a wafer or slice which constitutes the semiconductor part of a device or integrated circuit. Die are usually not separated until all of the wafer or slice processing is complete. They are usually too small to be processed individually.

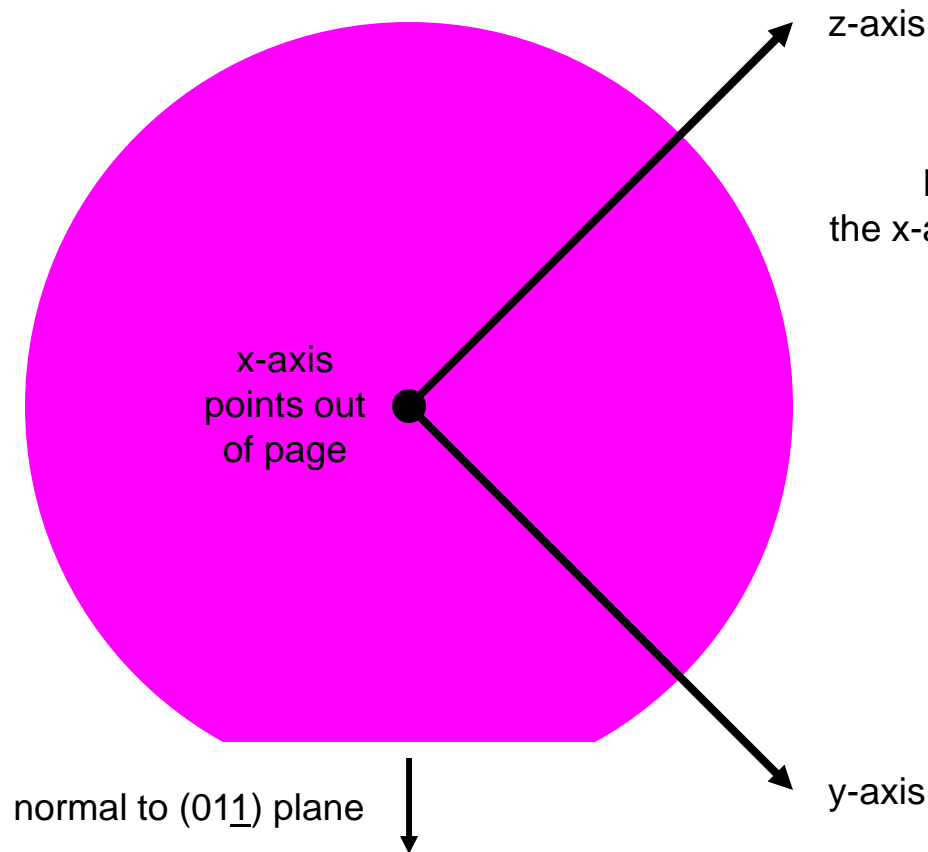
# Standard Wafer Features

- Surfaces
  - Top: ground, lapped, and polished.
  - Bottom: usually just ground; looks like a dull or matte finish.
- Orientation flats
  - Used to mark crystallographic orientation.
    - Primary flat indicates the  $(01\bar{1})$  plane for both (100) and (111) wafers.
  - Used also to distinguish n-type from p-type.
    - Position of the secondary (smaller) flat relative to the primary flat.
- Edge radius
  - Ground after wafers are cut from the parent boule.
  - Edge radius is usually half the wafer thickness.
- Serial number (on backside)
  - Optional; usually done by a laser marking system.



# Wafer Crystallographic Orientation

- Indexed by the primary flat which marks the  $(01\bar{1})$  plane:



Example for a  $(100)$  orientation wafer:  
the x-axis is normal to the top side wafer surface.

Note that the primary flat is normally at the bottom, as one is looking at the top side of the wafer. In this orientation, the flat is toward the person, and the flat is usually the spot chosen to grasp the wafer with wafer tweezers.

# Standard Silicon Wafer Grades

- Mechanical grade
  - Only the dimensions are controlled
- Furnace grade
  - Tightly controlled oxygen and carbon content, resistivity, and dopant uniformity
- Epi grade
  - Has a thin epitaxial film deposited over top to create a smoother, more defect free working surface
- Recycled/reclaimed grade
- Test grade
  - Most common for research purposes
  - A good compromise of quality to cost
  - No flatness or backside specs and a wide resistivity range
  - Usually a prime grade wafer that has failed a spec
- Prime grade
  - The best available and suitable for any state-of-the-art process at any major IC manufacturer
  - Essentially defect-free and usually expensive (up to ~10X the cost of test grade)

# Standard Silicon Wafer Sizes

- Minimum thickness is that usually needed for standard processing.
- Weight is that of a single wafer at this thickness.

diameter	min. thickness	no. in std. cassette	wafer weight
1.00 inch	250 $\mu\text{m}$	25	0.295 g
2.00 inch	280 $\mu\text{m}$	25	1.32 g
3.00 inch	380 $\mu\text{m}$	25	4.03 g
100 mm	525 $\mu\text{m}$	25	9.60 g
125 mm	575 $\mu\text{m}$	25	16.43 g
150 mm	625 $\mu\text{m}$	25	25.71 g
200 mm	700 $\mu\text{m}$	10	51.20 g
300 mm	775 $\mu\text{m}$	10	127.53 g

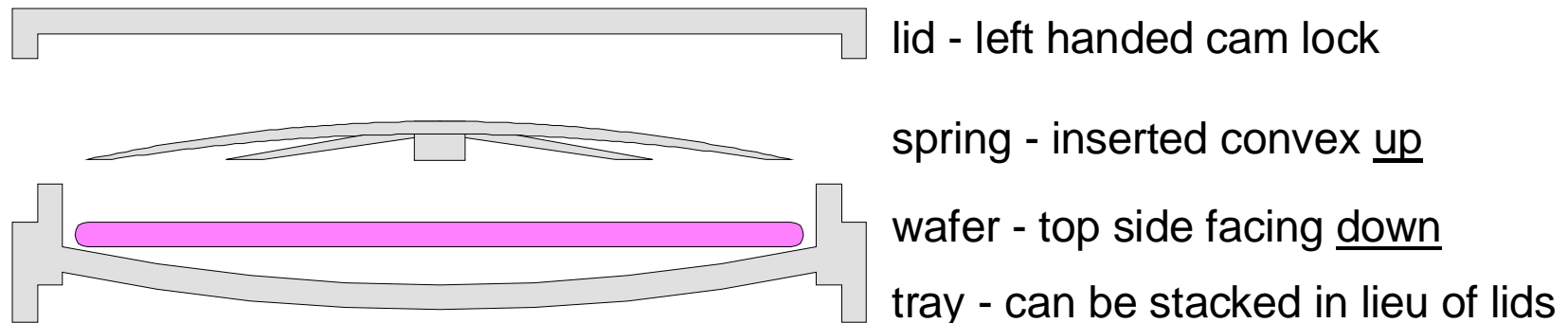
Note that silicon wafers can be custom ordered to nearly any thickness, from 50  $\mu\text{m}$  up to several mm thick.

# Wafer Storage Containers

- Wafer boxes or cassettes
  - Used to hold 25 wafers in one processing lot. (10 for big wafers)
  - Consist of a wafer carrier, a bottom and a top that latch together.
- Wafer trays
  - Used to hold a single wafer.
  - Consist of a bottom tray, a spring, and a lid to keep the wafer in place.
- Slice trays
  - Compartmentalized trays to hold several slices of a wafer.
  - Consist of a bottom, a top, and an external spring(s) to hold it closed.
- Die trays
  - Compartmentalized trays to hold many die of a wafer or slice.
  - Consist of a bottom, a top, and an external spring(s) to hold it closed.
  - Gel packs or gel trays are also commonly used for holding dice.

# Wafer Tray Assembly

- Standard Fluoroware® design – polypropylene material.
- Available for 1, 2, 3 – inch; 100, 125, 150 mm wafers.
- Tray and spring should only contact the wafer on the edges.
- Can and should be cleaned with solvents prior to loading.



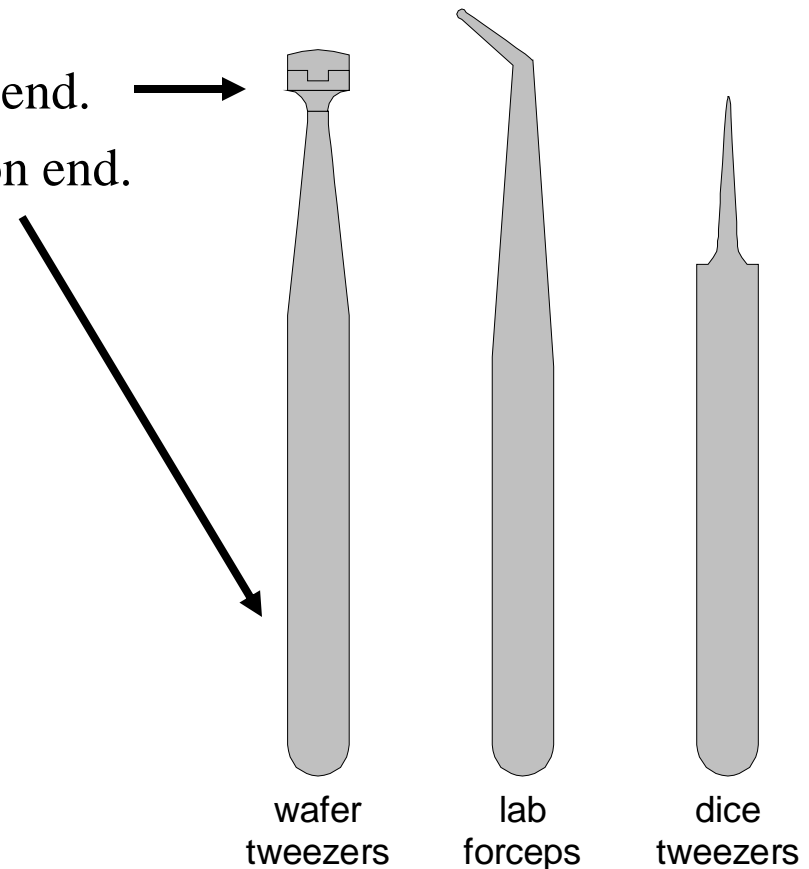


## Wafer Handling

- Wafers are never handled directly by hand.
  - Only wafer tweezers or vacuum wands contact wafers in process.
- Wafer tweezers:
  - Have a sharpened scoop, shovel, or blade end which is designed to slide underneath the rounded edge of a wafer.
  - Have a blunt pincer or foot which clamps the wafer against the blade.
  - Are useless for slices or die with square edges.
  - Are sized according to wafer diameter (up to 6-inch wafers)
  - The foot has 3 toes for a 3-inch wafer, 4 toes for a 4-inch wafer, etc.
- Vacuum wands:
  - Have a vacuum paddle which is designed to contact the wafer from the backside.
  - Only useful if the backside of the wafer is directly accessible.

# Use of Tweezers

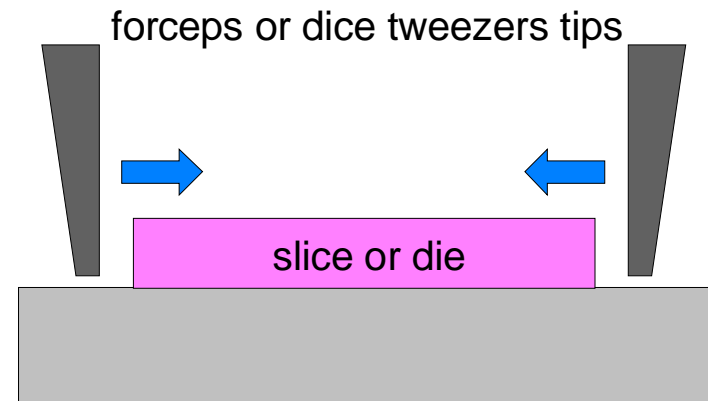
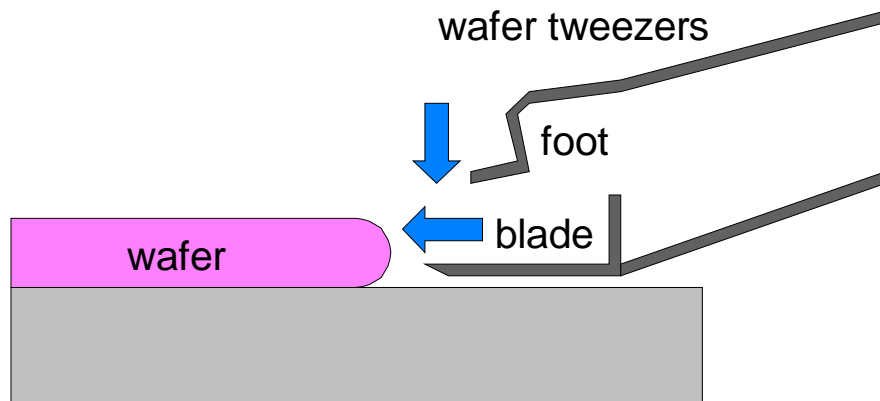
- Proper use of tweezers creates the primary barrier against contamination propagation:
  - A wafer touches only the wafer end.
  - A person touches only the person end.
- Types:
  - Wafer tweezers: for wafers
  - Lab forceps: for slices
  - Dice tweezers: for dice
- Tweezers storage:
  - Tweezers case
  - Glass jar with lid
  - Clean room toolbox



Be careful not to damage the points of dice tweezers!

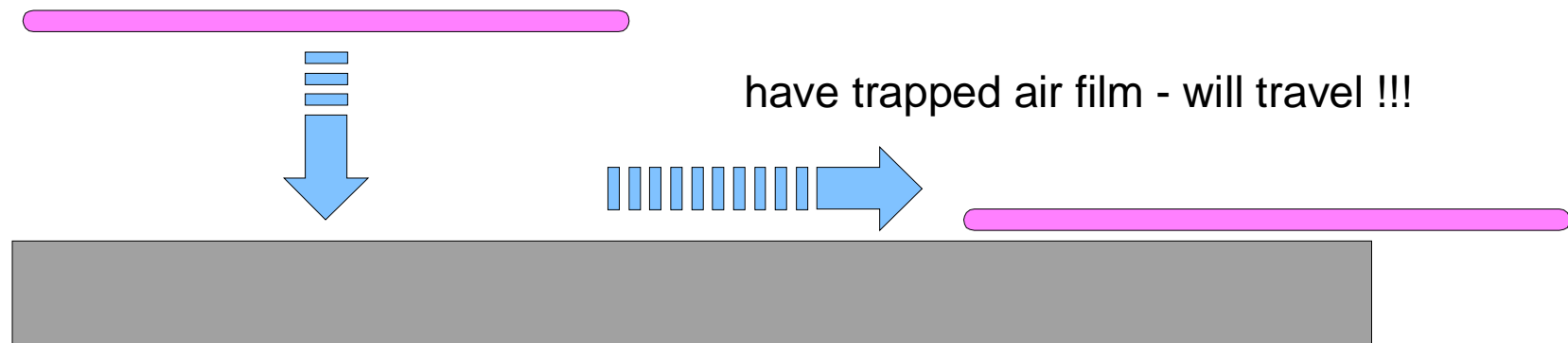
# Picking Up Wafers, Slices, and Dice

- It all depends upon whether the edge is rounded or square:
  - Wafer tweezers have a sharpened blade which can be slipped underneath the rounded edge of a wafer.
  - Engage the blade up to the stop. Ensure that the foot of the wafer tweezers has a solid purchase before moving the wafer.
  - Lab forceps or dice tweezers are needed to grasp the square edges of slices or dice.

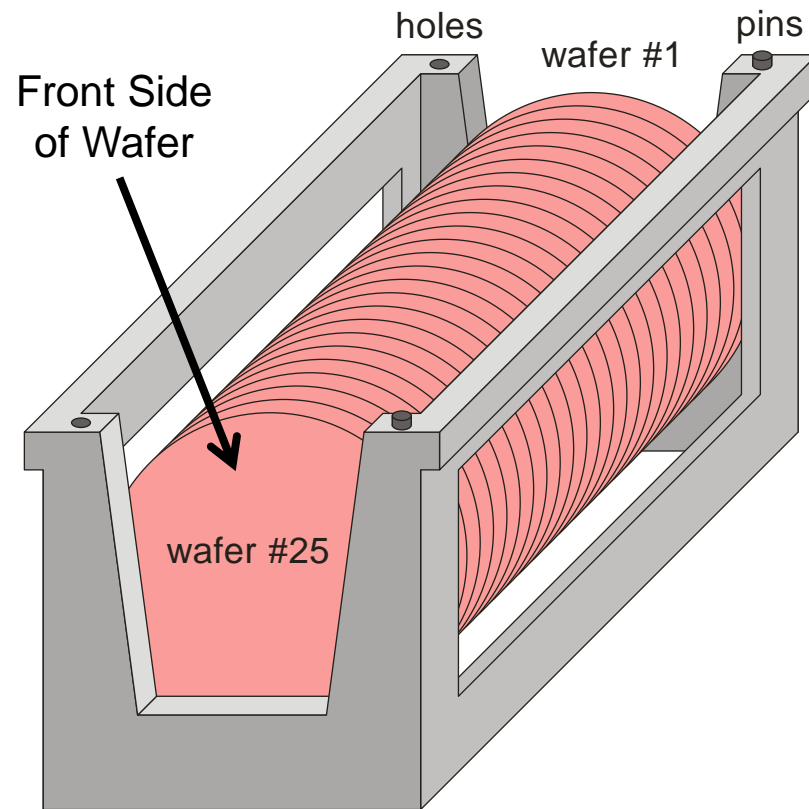


## Placing Wafers on Chucks

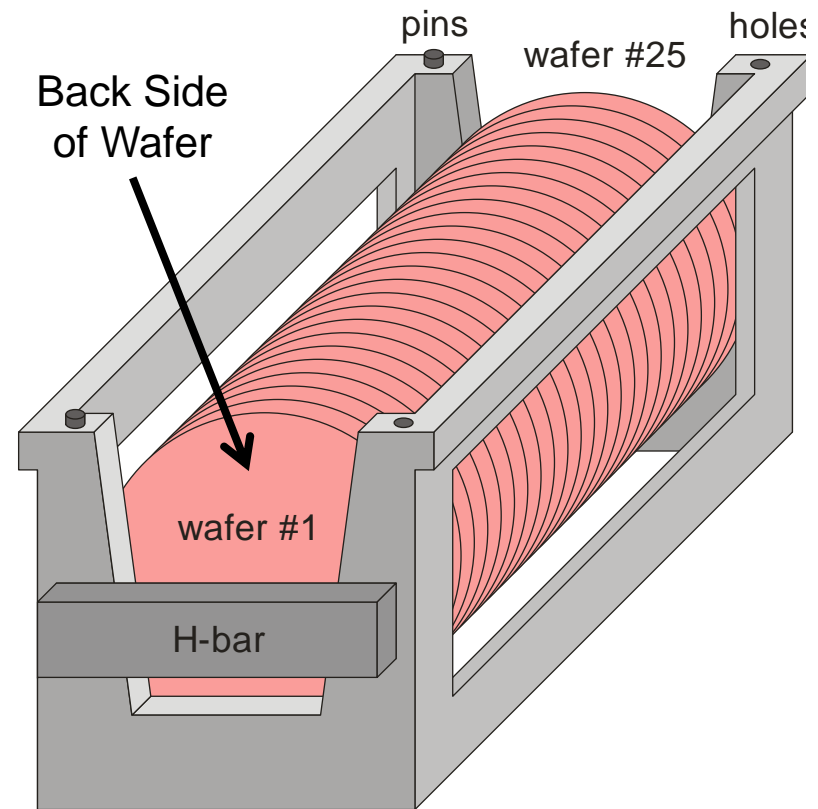
- The trapped air film between the bottom of a wafer and the chuck or work table can cause wafers to skid large distances!
  - The floor may become the final parking lot.
- Use wafer tweezers to place the wafer accurately in position, and then release. Do not just let the wafer drop.



# Wafer Cassettes



front/top side of cassette  
front/top side of wafers



back/bottom side of cassette  
back/bottom sides of wafers

Wafer #1 is closest to the H-bar, and would be loaded into an automatic machine first.

## Use of Wafer Cassettes

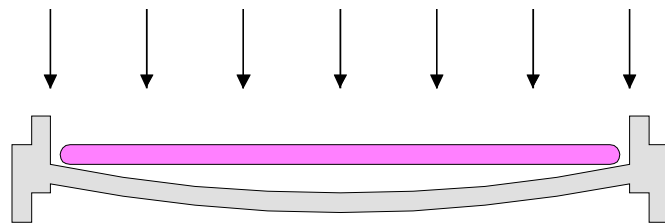
- Orientation matters!
  - Wafer cassettes are used to load a set of wafers into many different types of processing equipment. To index the cassette to the handler, an H-bar is located on the BOTTOM of each cassette.
  - The good (top) side of each wafer should face AWAY from the H-bar.
- Cassette material matters!
  - Use only PFA cassettes for wet etching or cleaning.
  - Use the wafer box cassettes only for storage.
  - Use metal or quartz cassettes for plasma cleaning or wafer priming.
- Transfer into and out of cassettes:
  - Use wafer tweezers for moving only a subset of the wafers.
  - All 25 wafers can be transferred at once between two cassettes by matching up their pins and holes and rolling the wafers from one into the other. Exercise great care when doing this!

# Common Wafer Contaminants

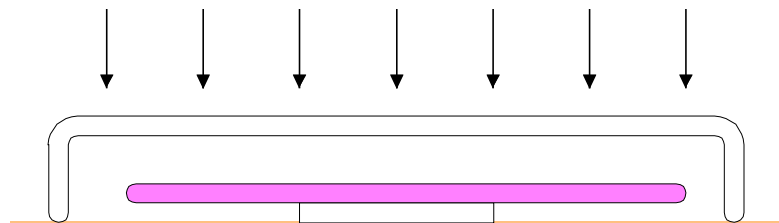
- Surface oxides
  - native oxides
  - metal oxides from prior processing steps
- Non-reactive dust
  - not chemically bound, but often electrostatically or van der Waals bonded to the wafer surface
- Water marks
  - precipitated salts and organic debris after water has evaporated
- Chemical residue
  - residual photoresist, wafer primers, plasticizers, pigments, ballasting resins
- Organic films
  - oils, waxes, greases, carbonized residue

## Keeping Wafers Clean While In Process

- Most air flow in a clean room is down.
- Gravity also sends suspended particles in the air down.
- Wafers that are face-up will accumulate more particulate contamination than wafers which are face-down.
- 2 solutions:
  - Place wafers in process (WIP) face down in wafer trays while in between processing steps.
  - Place wafers in process (WIP) face up on top of a clean filter paper and microscope slide and underneath a petri dish cover.



wafer upside down in wafer tray



wafer rightside up on microscope slide  
petri dish cover keeps particles off



## Watch Your (Wafer's) Backside!

- Vacuum chucks are notorious for sucking excess wet material around to the backside of a wafer.
- This is especially a problem with goopy unbaked photoresist.
- Wet photoresist or other material on wafer backside can subsequently glue the wafer down on to the next surface.
  - Common example: wafer comes off of photoresist spinner chuck and then on to hot plate. If there is any wet photoresist on the backside, the hot plate will cook this and glue the wafer on to the hot plate surface.
  - ALWAYS check the backside for this problem before hot plating.
  - ALWAYS keep the spinner chucks spotlessly clean to avoid this.
  - ALWAYS check to insure the right size spinner chuck is in use.

# The Spectrum of Wafer Cleaning Methods

- Acid / alkali – oxide etch
  - used to remove native and non-native oxides
- Plasma oxygen ashing
  - used to remove organic films and residues
- Ultraviolet-ozone clean
  - used to remove organic films and residues
- Solvent clean
  - used to remove oils, greases, waxes, and carbonized residues
- De-ionized water clean
  - used to remove all loose material

# RCA Wafer Clean

- Developed by Kern and Puotinen at RCA in 1960.
- The standard for the semiconductor industry up through the present.
- Standard Cleaning solution 1 (SC-1 or APW):
  - $\text{NH}_4\text{OH} : \text{H}_2\text{O}_2 : \text{H}_2\text{O}$  @ 1:1:5 to 1:2:7 ratio of standard concentrations.
  - Etch at 70-80°C.
  - High pH (basic) solution removes organics, carbonized residues, and chemically-bound surface particles by oxidation.
- Standard Cleaning solution 2 (SC-2 or HPW):
  - $\text{HCl} : \text{H}_2\text{O}_2 : \text{H}_2\text{O}$  @ 1:1:6 to 1:2:8 ratio of standard concentrations.
  - Etch at 70-80°C.
  - Low pH (acidic) solution desorbs and leaches out metals.
- Both of these solutions will produce some oxidation of a silicon wafer.
  - This can be removed by another BOE etch as part of the overall process.

# Standard Wafer Clean with Oxide Strip

1. SC-1: 1:3:15  $\text{NH}_4\text{OH} : \text{H}_2\text{O}_2 : \text{H}_2\text{O}$  @ 75°C for 15 min.
2. DI  $\text{H}_2\text{O}$  rinse @ RT for 5 min.
3. 10:1 BOE @ RT for 1 min. (this is what strips the oxide)
4. DI  $\text{H}_2\text{O}$  rinse @ RT for 5 min.
5. SC-2: 1:3:15  $\text{HCl} : \text{H}_2\text{O}_2 : \text{H}_2\text{O}$  @ 75°C for 15 min.
6. DI  $\text{H}_2\text{O}$  rinse @ RT for 5 min.
7. Spin, rinse, & dry –
  - use an automated SRD for best results and sparkling clean wafers.

## Notes:

Exact proportions of SC-1 and SC-2 solutions vary from lab to lab. (Often passionately!)

Standard wafer clean is used for any new wafer prior to any processing.

RT = Room Temperature, i.e. non-critical, but around 21°C.

10:1 BOE is usually available as a premixed buffered solution of  $\text{NH}_4\text{F}$  and HF.

# Piranha Etch

- An extremely aggressive etch for organic residue.
- $\text{H}_2\text{SO}_4$  :  $\text{H}_2\text{O}_2$  @ 4:1 standard concentrations.
- Etch at 90°C for 10 minutes.
- Mixing of acid and peroxide is extremely exothermic – mixture often reaches the boiling point all on its own.
- The pot life is fairly short – only 20-30 minutes before the peroxide is decomposed by the heat of the solution.
- This etch solution must be treated with great respect and care.

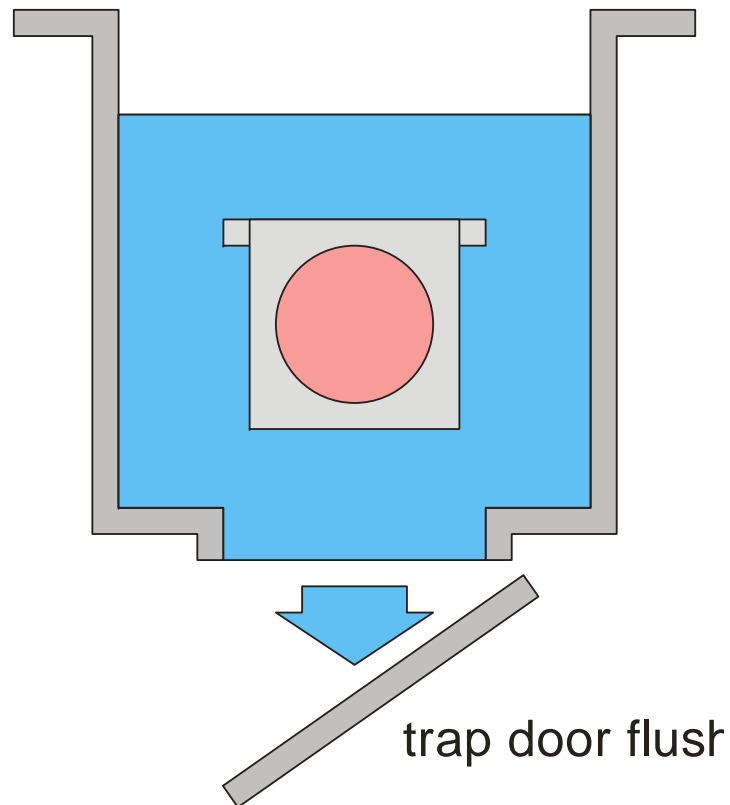
## Wet Bench Etch Pots

- Wet etching and wafer cleaning are carried out in wet benches which have built-in chemical etch pots.
- There are many features that may be found on these:
  - Built-in heater and temperature controller
  - Built-in recirculation pump
  - Built-in agitation: a stirring paddle wheel or nitrogen gas bubbler
  - Built-in filling control
  - Built-in waste dump control
  - Electronic timers for the etch
- Wafers are typically moved into and out of the etch pots in wafer carriers which are constructed of PFA or similar inert materials which will withstand the chemistry.

## Wet Bench Rinsers

- Wet chemical processing involves a significant amount of DI water rinsing to clean off the previous etchant.
- The objective is to dilute and flush away the residual etchant and any matter that may be dissolved in it without allowing the water to evaporate and leave water spots.
- Quick dump tanks
  - Fast but uses a lot of DI water.
  - Typically about 1 min. to fill and 5 seconds to dump (flush).
- Cascade rinsers
  - Slower but more economical with DI water usage.
  - Typically about 3-5 mins. rinse time per stage.

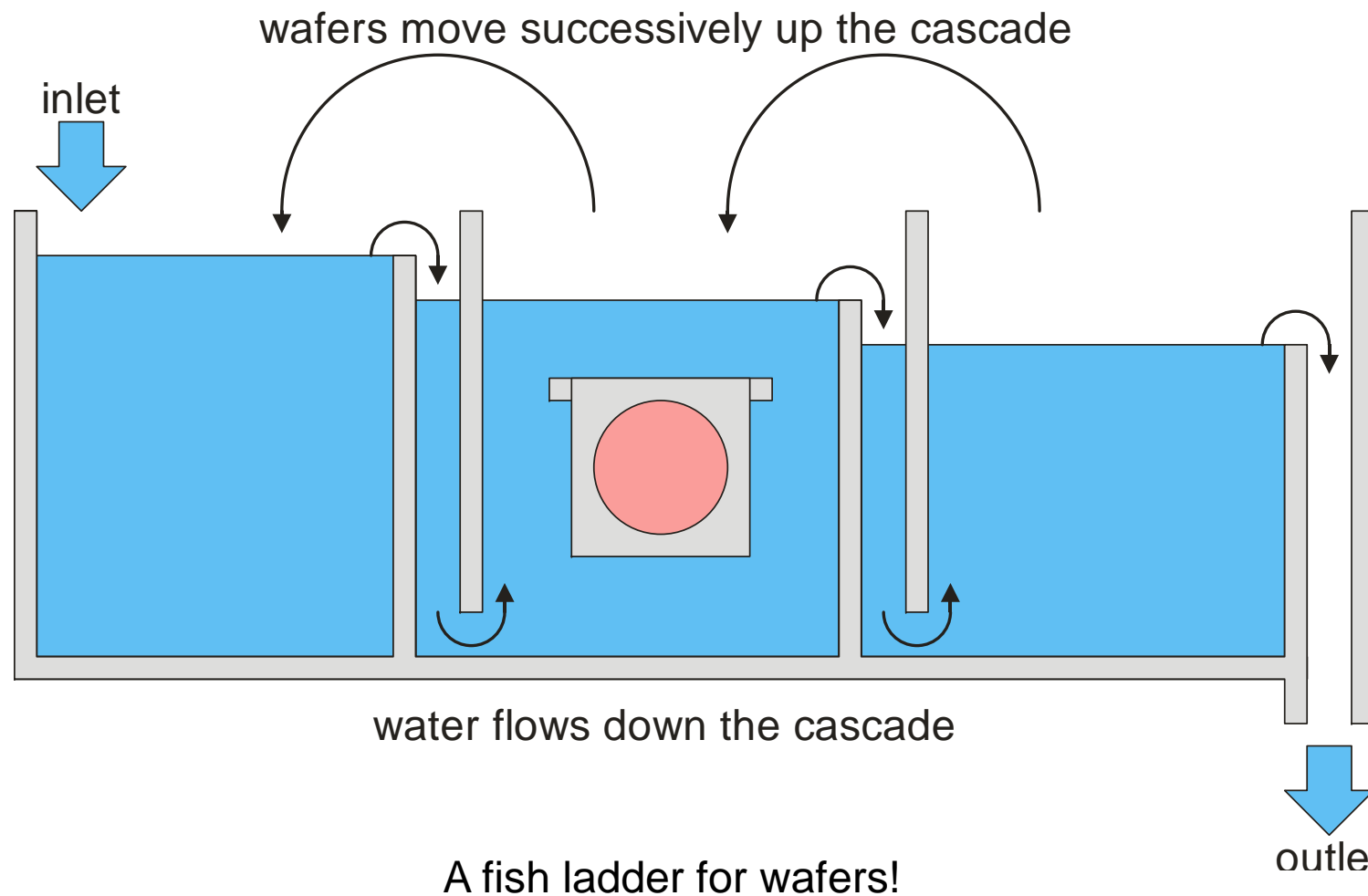
# Quick Dump Tank



The closest analog is a toilet.



# Cascade Rinser

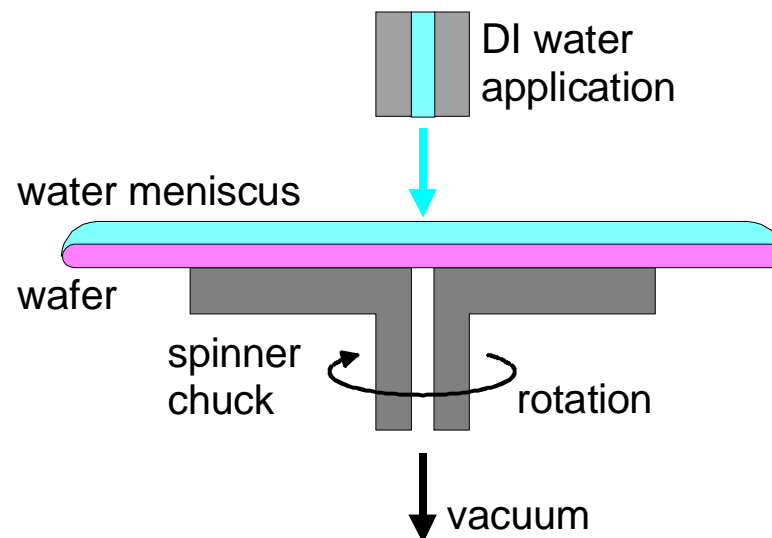


## Drying Wafers

- Excess water must be blown off of the wafers, or other parts being cleaned, because water left to evaporate will leave water spots.
- Water spots are precipitated salts and organic matter that was dissolved or suspended in the water before it evaporated.
- Air guns, usually blowing dry nitrogen, can be used for some wafer drying, but achieving uniformity and consistency is very difficult.
  - Also, it is very easy to launch a wafer airborne by careless use of the dry nitrogen gun.
- Air knives are arrays of jets that the wafer passes through which blow the excess water off in one direction.

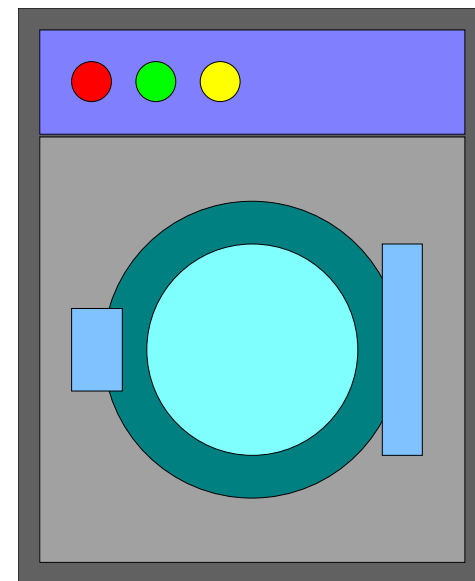
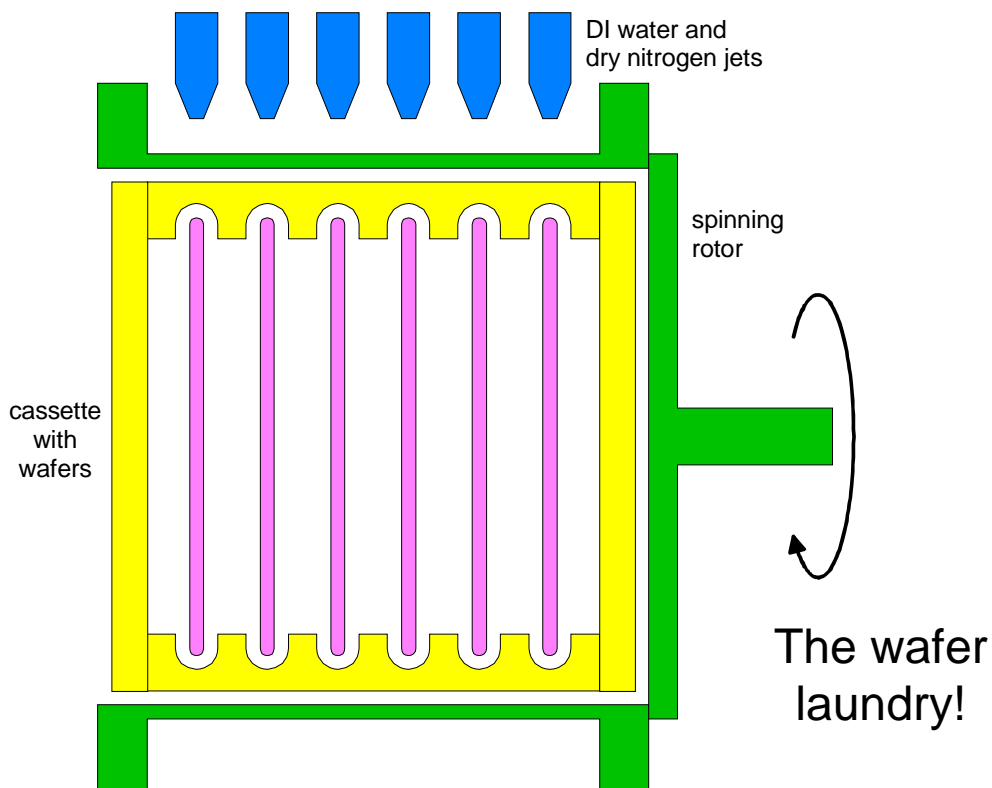
## Spinner Chuck Rinse and Dry

- The simplest way for achieving reasonable cleaning and drying in a research environment.
  - Wafer is placed on spinner chuck & held down by vacuum
  - Fresh meniscus of DI water is added to surface, before any existing water has had a chance to evaporate
  - Spinner is ramped up and excess water is slung off
  - Any residual water and/or water spots will be only on the back side



# Spin Rinse Drier (SRD)

- A system for spinning, rinsing, and drying an entire cassette of wafers (usually 25) at once.
- Runs on DI water, dry nitrogen, and a spinning rotor which accepts a standard wafer cassette; ~1000-2000 rpm.
- Provides the best overall final cleaning of wafers, both front and back.



## SRD Recipes

- Most common recipe for a “standard” wafer wash:
  - 1-2 mins. @ 300 rpm with DI water spray and N<sub>2</sub> blow
  - 3 mins. @ 2000 rpm with N<sub>2</sub> blow and heat
- Always use a DI water quench bath after any etch step and before any SRD wash.
  - Do not contaminate the SRD with any etch residue!
- Make certain that the wafer size matches the rotor size of the SRD.
  - The cassette should be a close fit to the rotor cavity.
- Note that SRDs use a LOT of water and nitrogen!
  - Plan ahead for big drains and large N<sub>2</sub> feeds.
- Take your wafers to the laundry often!

# Solvent Cleaning

- Non-polar solvents are used to remove non-polar aliphatic hydrocarbons, such as oils, waxes, greases, and carbonized residue.
- Polar solvents, such as water, will not effectively remove non-polar hydrocarbons because they will bead up on the hydrocarbon:
  - The hydrocarbon is not wetted by the water, or said differently,
  - The hydrocarbon is hydrophobic.
- Detergents can also be used to remove hydrophobic residues, but these leave behind their own residue and do not really solve the problem.
- Volatile solvents allow hydrophobic residues to be removed, and then they simply evaporate leaving behind no residue of their own.
- Like water, solvents must be flushed from the wafer, rather than being allowed to evaporate.
- Each successive flushing uses a progression of solvents with increasing polarity, eventually matching to that of water, which is the final solvent.

# Common Microelectronics Solvents

- De-ionized water:  $\text{H}_2\text{O}$  (DI) (not flammable) white wash bottle
- Alcohols: (flammable)
  - Methanol,  $\text{CH}_3\text{OH}$  (MeOH) – highly toxic green wash bottle blue wash bottle
  - Ethanol,  $\text{CH}_3\text{CH}_2\text{OH}$  (EtOH) orange wash bottle
  - Isopropanol,  $\text{CH}_3\text{CHOHCH}_3$  (IsOH) yellow wash bottle
- Ketones: (flammable)
  - Acetone,  $\text{CH}_3\text{COCH}_3$  (Actn) – extremely flammable! red wash bottle
  - Methyl isobutyl ketone,  $(\text{CH}_3)_2\text{CHCH}_2\text{COCH}_3$  (MIBK)
- Halogenated hydrocarbons: (not flammable)
  - Carbon tetrachloride,  $\text{CCl}_4$  (Ctet) – carcinogenic
  - Trichloroethylene,  $\text{C}_2\text{HCl}_3$  (TCE) – carcinogenic
  - 1,1,1-Trichloroethane,  $\text{CH}_3\text{CCl}_3$  (TCA)

# Solvent Degrease

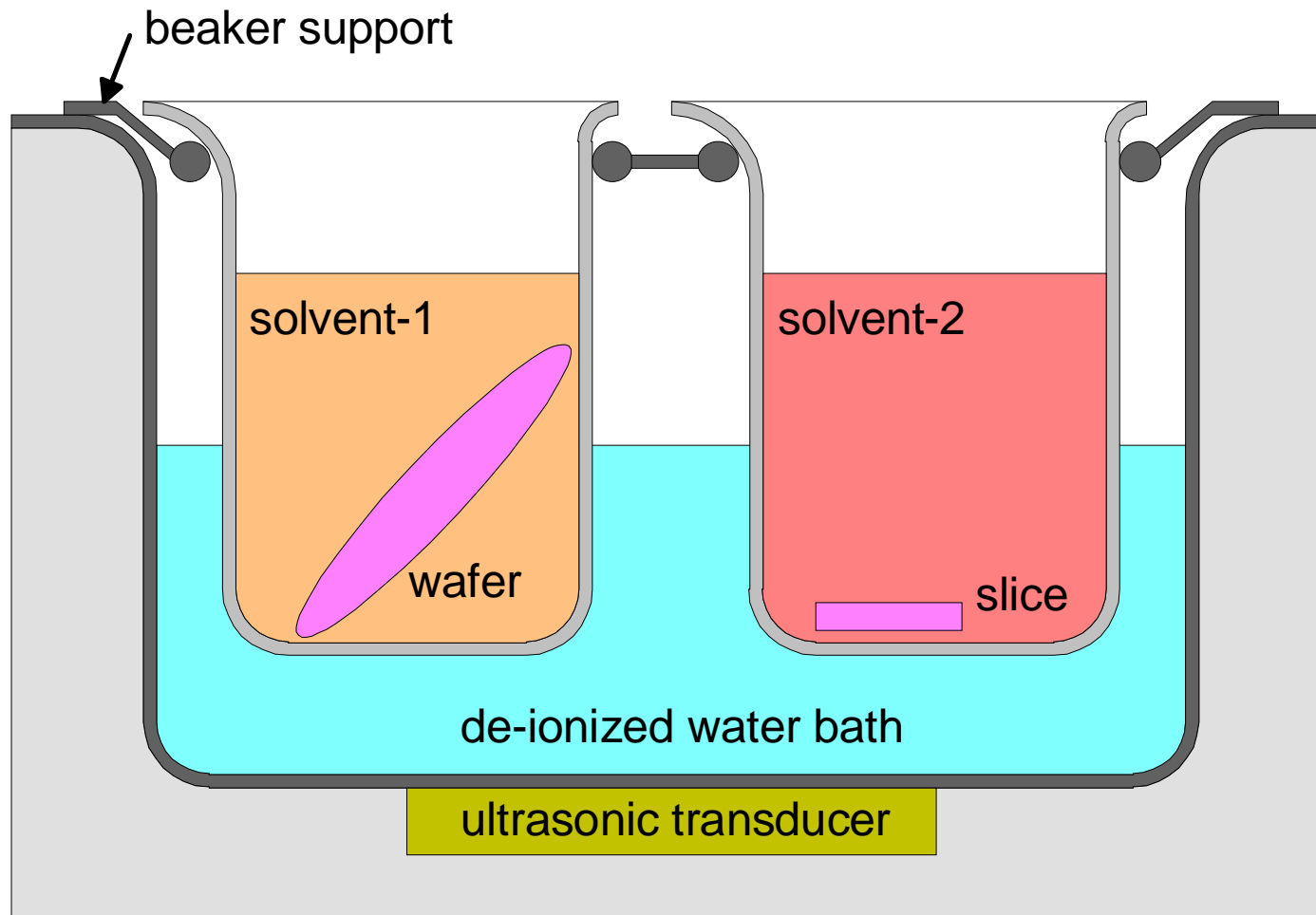
- Used to clean any mechanical parts or apparatus brought into the clean room.
  - Tools, tweezers, chucks, equipment components, etc.
- A sequence of solvents, progressing from non-polar to polar:
  - Trichloroethylene (TCE); substitute trichloroethane (TCA) for safety
  - Acetone (Actn); watch out for the flammability!
  - Methanol (MeOH); substitute isopropanol (IsOH) for safety
  - Deionized water (DI); blow dry with N<sub>2</sub> to eliminate water spots
- Parts are placed into a beaker of solvent and beaker is placed into a water bath ultrasonic cleaner for ~5-10 minutes for each solvent.



# Ultrasonic Cleaning

- Ultrasonic transducer on side of bath: 20 – 50 kHz
- Low power levels: ~10-100 Watts
  - Agitation: vibration of solvent against surfaces of parts can assist in removing particles and residues which are only physically bound to the surfaces.
- High power levels: ~100-1000 Watts
  - Cavitation: bubble formation and collapse produces scouring action on surfaces of parts.
- Power transfer is controlled by acoustic coupling of bath to solvent container to parts.
- Must be used with care: with too much power an ultrasonic cleaner can shred a delicate microstructure!

# Ultrasonic Cleaner



## A Final Note: The Spectrum of Cleanliness Needs

- Mechanical applications (low)
  - Example: MEMS, microfluidics, wafer scale artwork
- Microelectronics applications (high)
  - Example: CMOS, discrete transistors & diodes
- Optoelectronics applications (very high)
  - Example: photodetectors, imagers, LEDs, laser diodes
- Nanoscience and Surface Science applications (super high)
  - Example: AFM, STM, nanolithography